Optic Nerve Sheath Mechanics and Permeability in VIIP Syndrome

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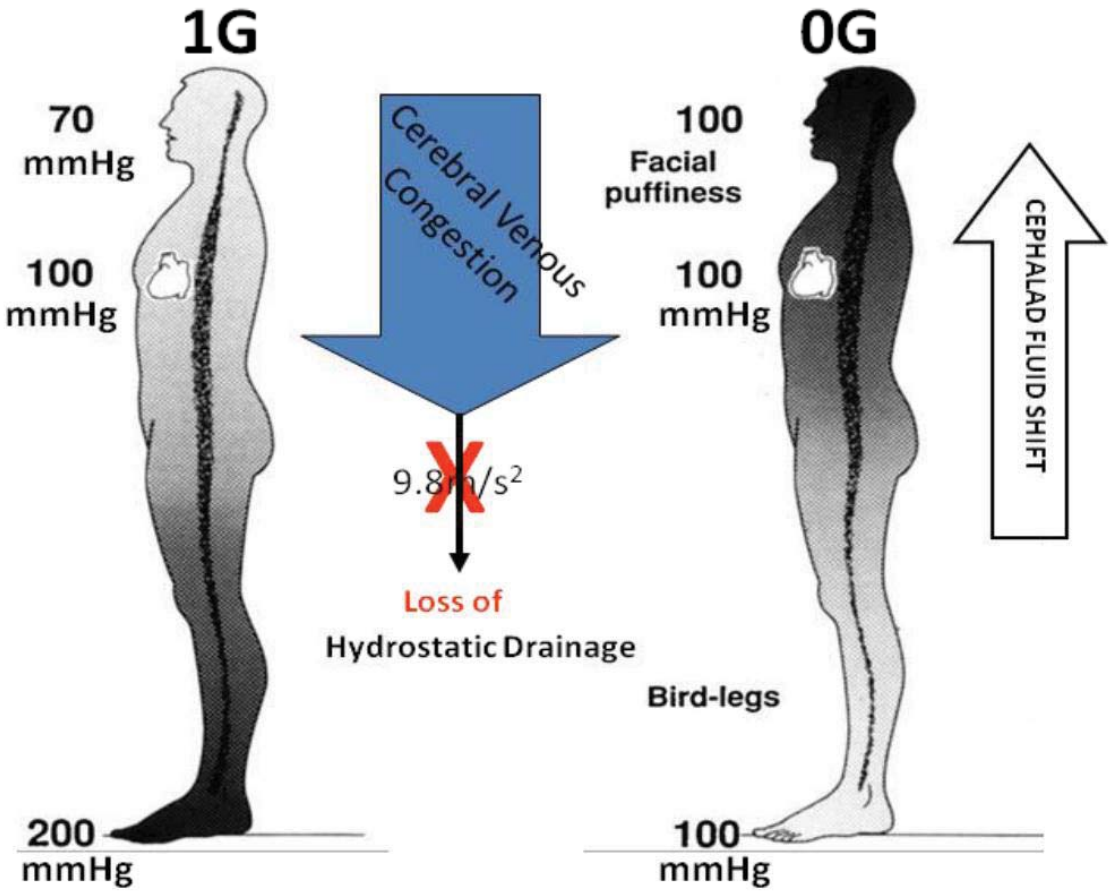
Disclosure

- **N**: None of the authors have any commercial relationships

Visual Impairment and Intracranial Pressure Syndrome (VIIP)

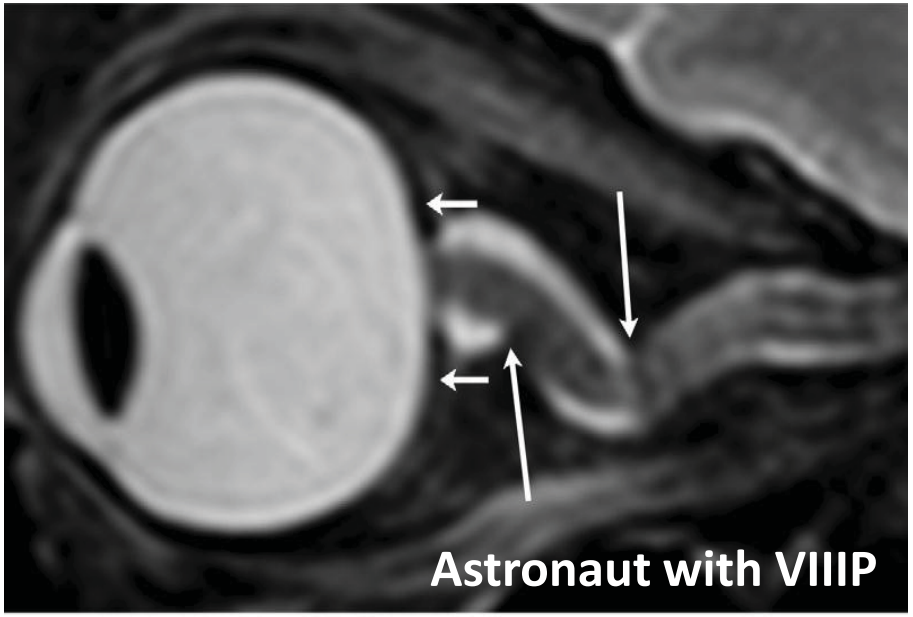
- Altered visual function following long-duration space flights
- 41.7% incidence in the U.S.
- Physiological adaptations to microgravity
- Cephalad fluid shifts

Cephalad Fluid Shifts



humanresearchroadmap.nasa.gov

Structural Changes in the Optic Nerve



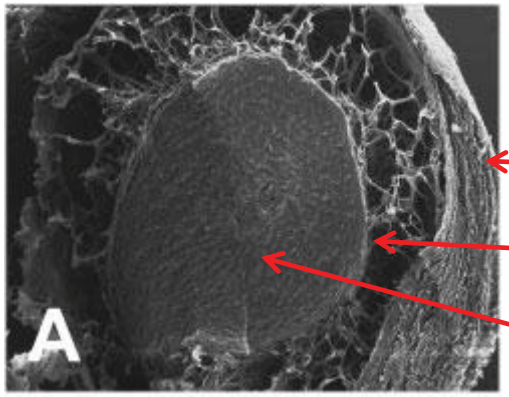
Tortuous optic nerve observed in an astronaut with visual disturbances following long duration space flight. Taken from Kramer et al. Radiology, 2012.

- Goal: study the mechanical properties of the optic nerve sheath at various CSF pressures to understand visual disturbances that occur during long-term space travel

- Hypothesis: increased CSF pressure drives remodeling of the posterior eye and the optic nerve sheath

Optic Nerve: Anatomy

Cross Section



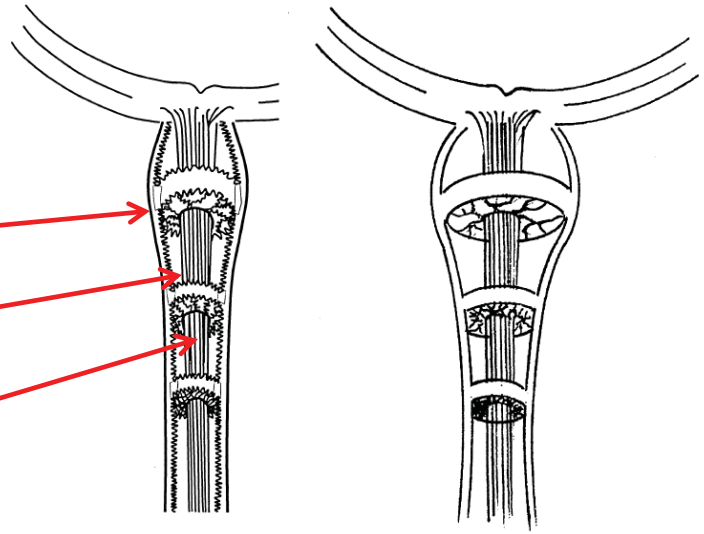
Killer et al. Brain, 2006.

Dura

Pia

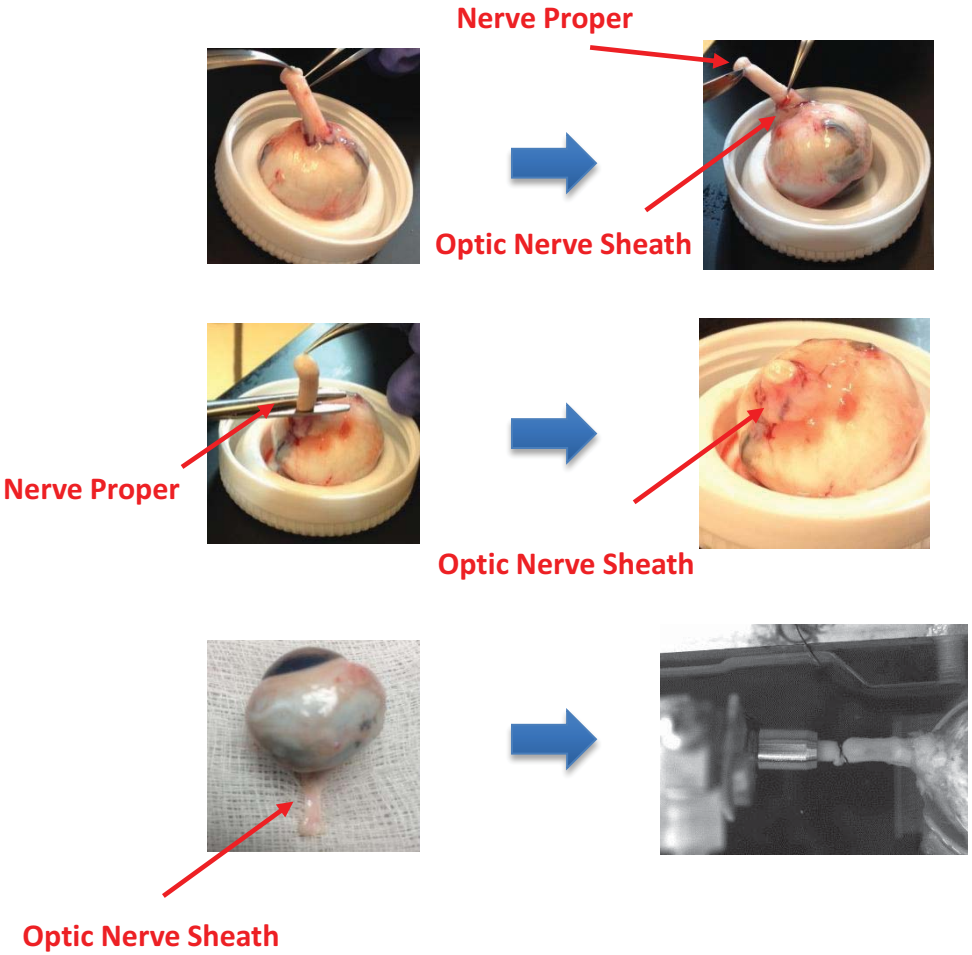
Nerve Proper

Low Pressure **High Pressure**



Hansen et al. Acta Ophthalmologica, 2011.

Experimental Protocol

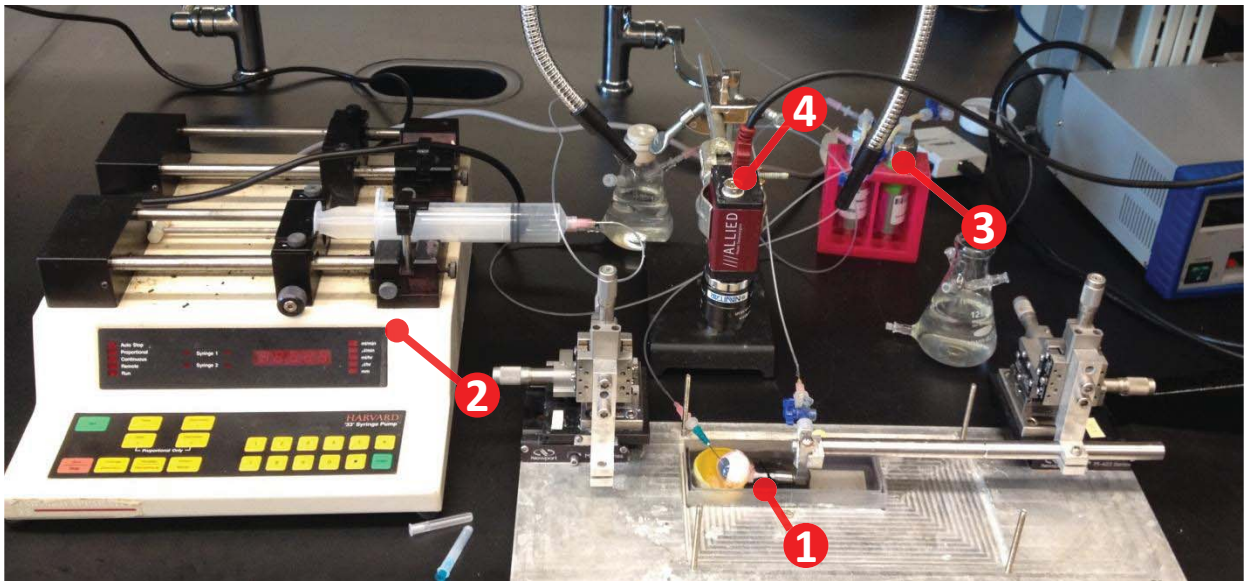


1. Sheath is peeled away from the nerve proper

2. Nerve proper is cut away

3. The optic nerve sheath is cannulated and connected to a pressure control system

Experimental System



System Components:

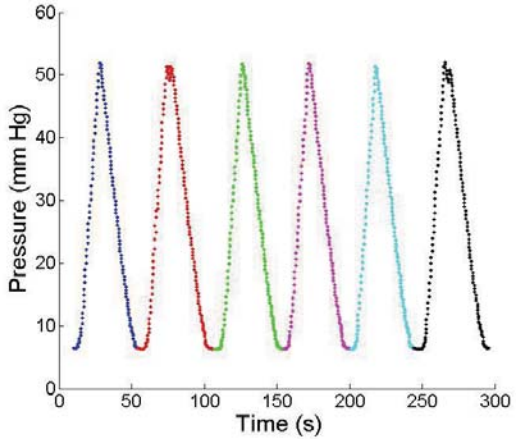
1 - Specimen bath/mounted porcine eye

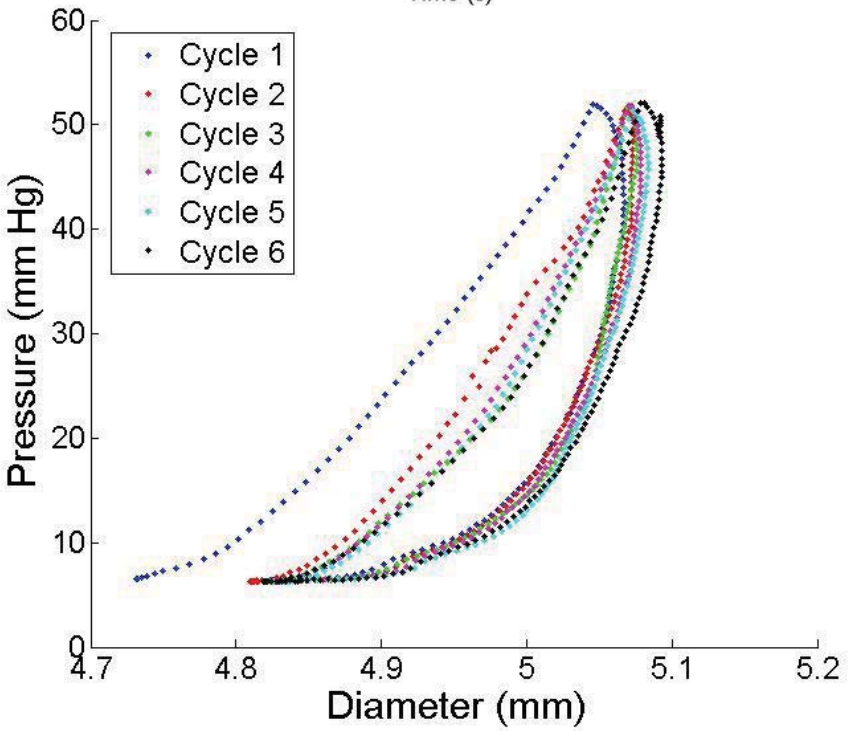
2 - Syringe pump

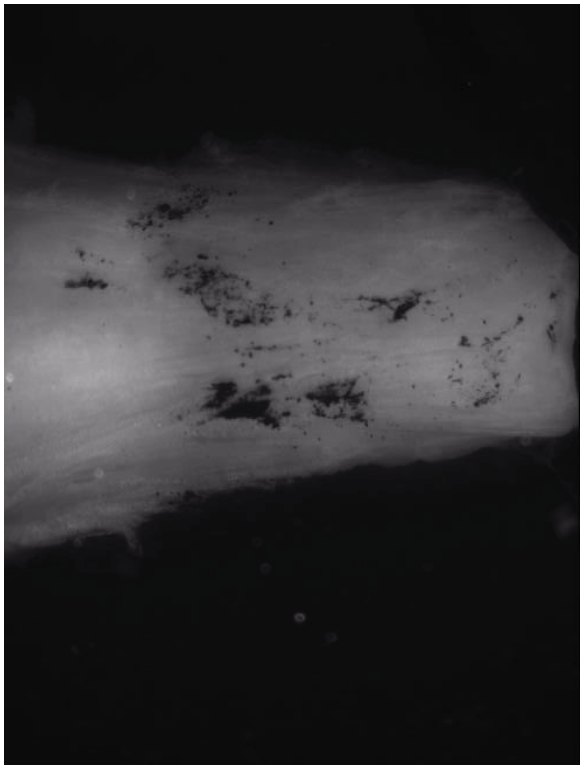
3 - Pressure transducers

4 - CCD camera

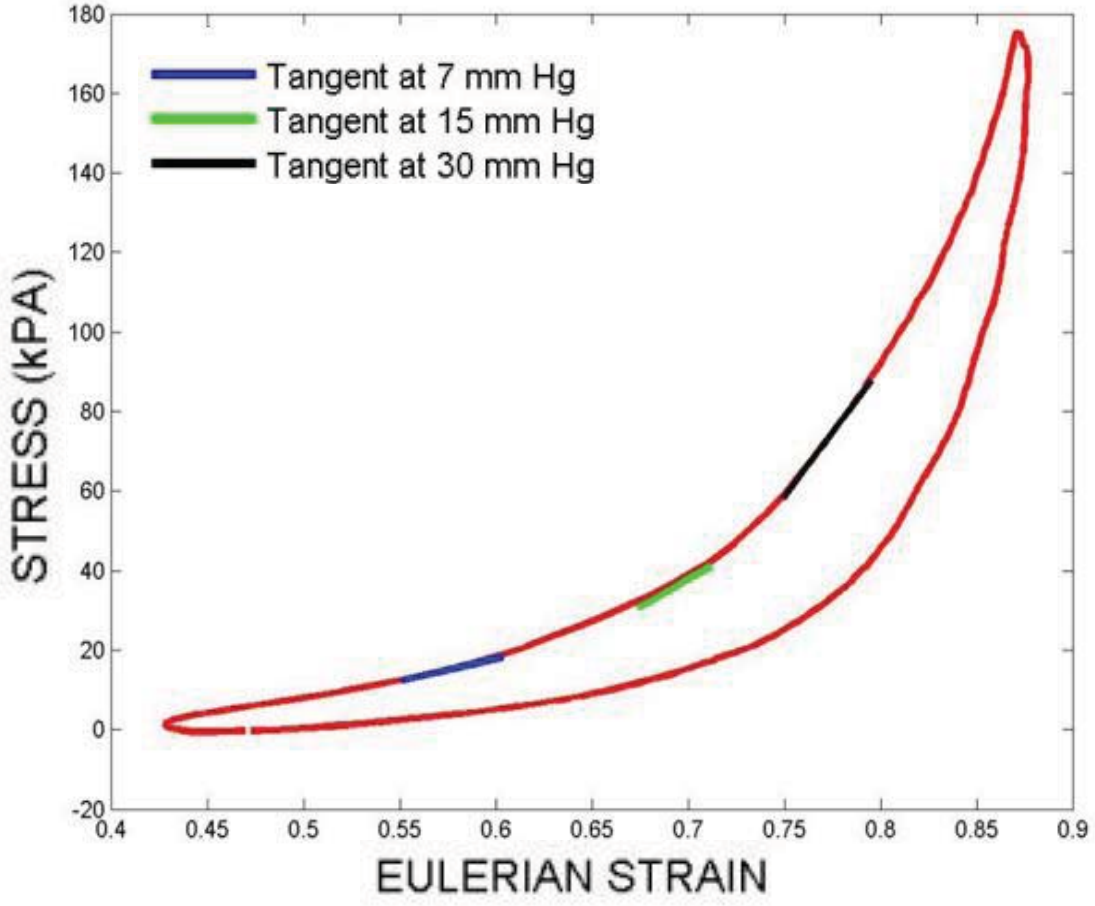
Pressure-Diameter Tests

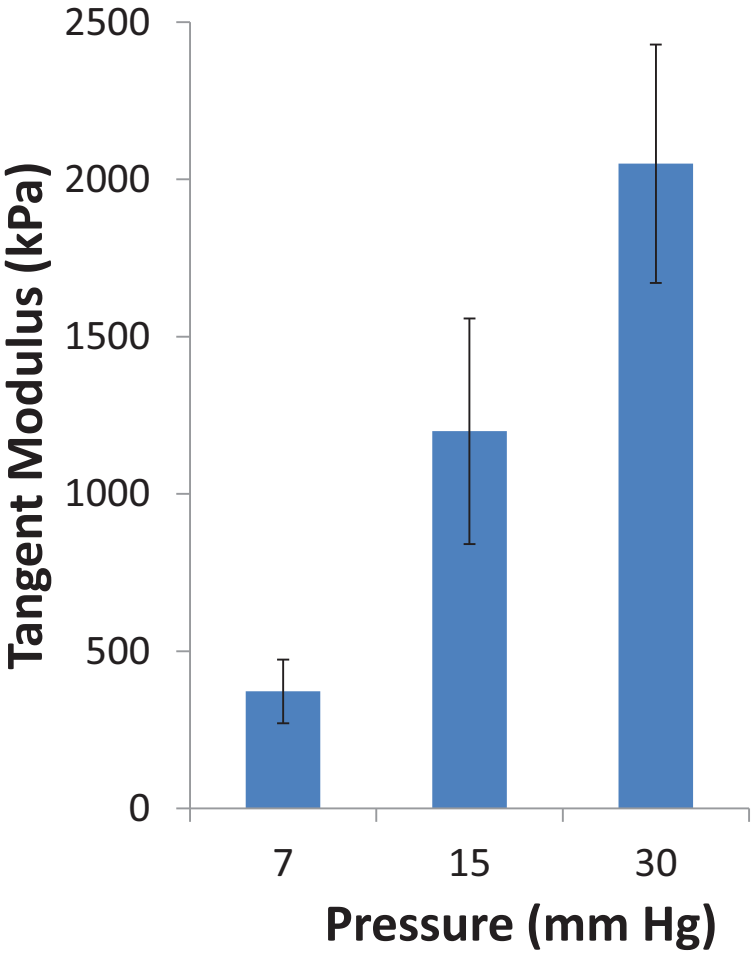






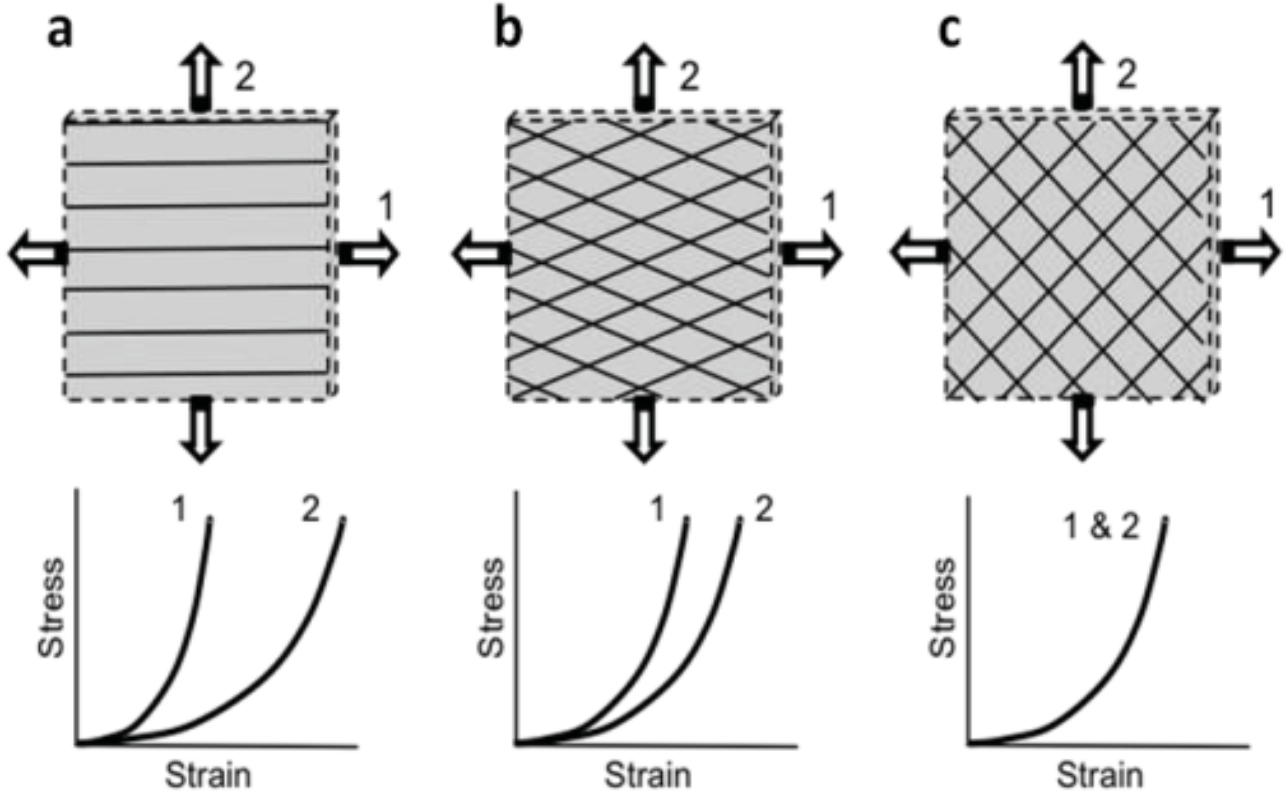
Modulus Increases at Higher Pressures



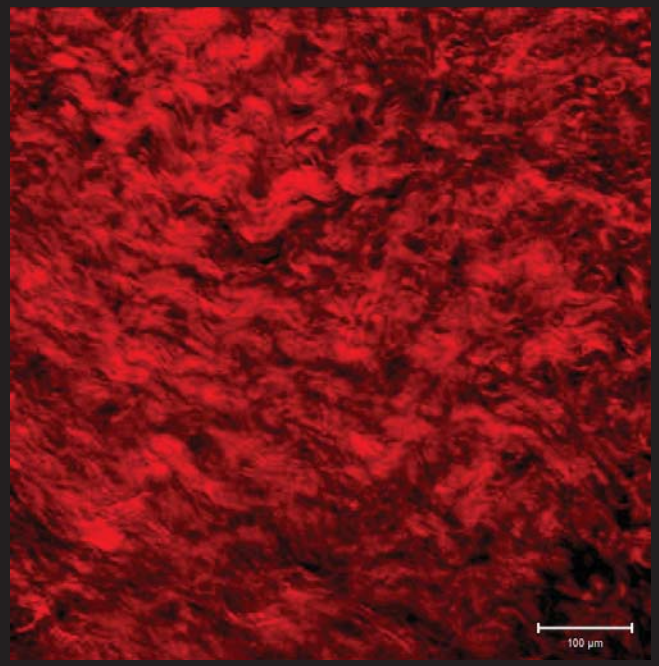


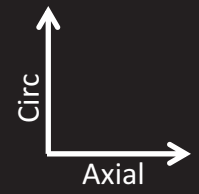
$$\varepsilon = \frac{r}{r_o} - 1 \qquad \sigma = \frac{Pr}{h}$$

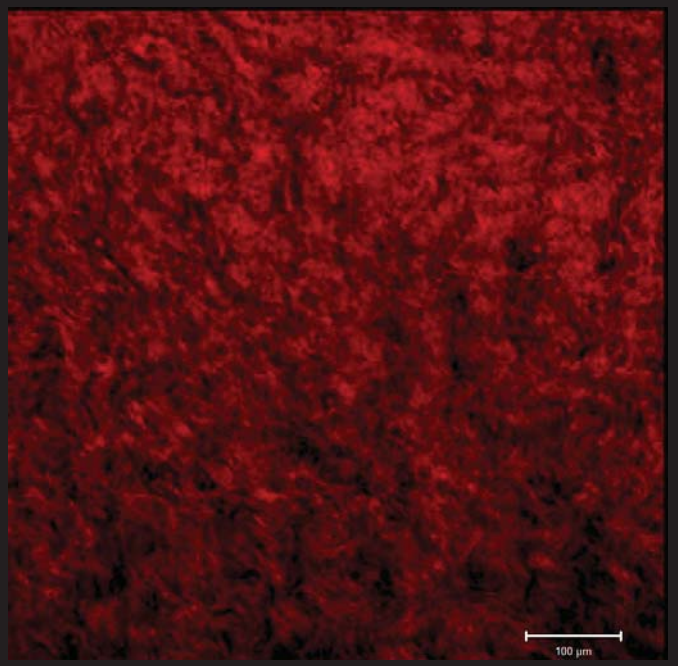
Collagen Fiber Orientation

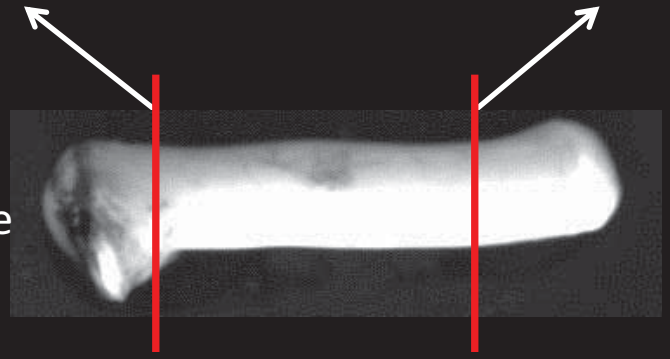


Collagen Orientation Changes with Distance from the Globe

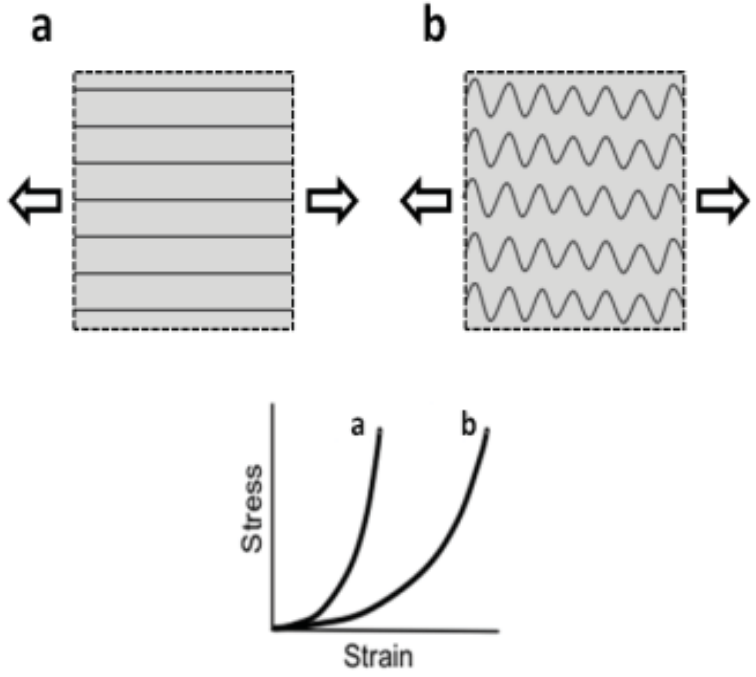




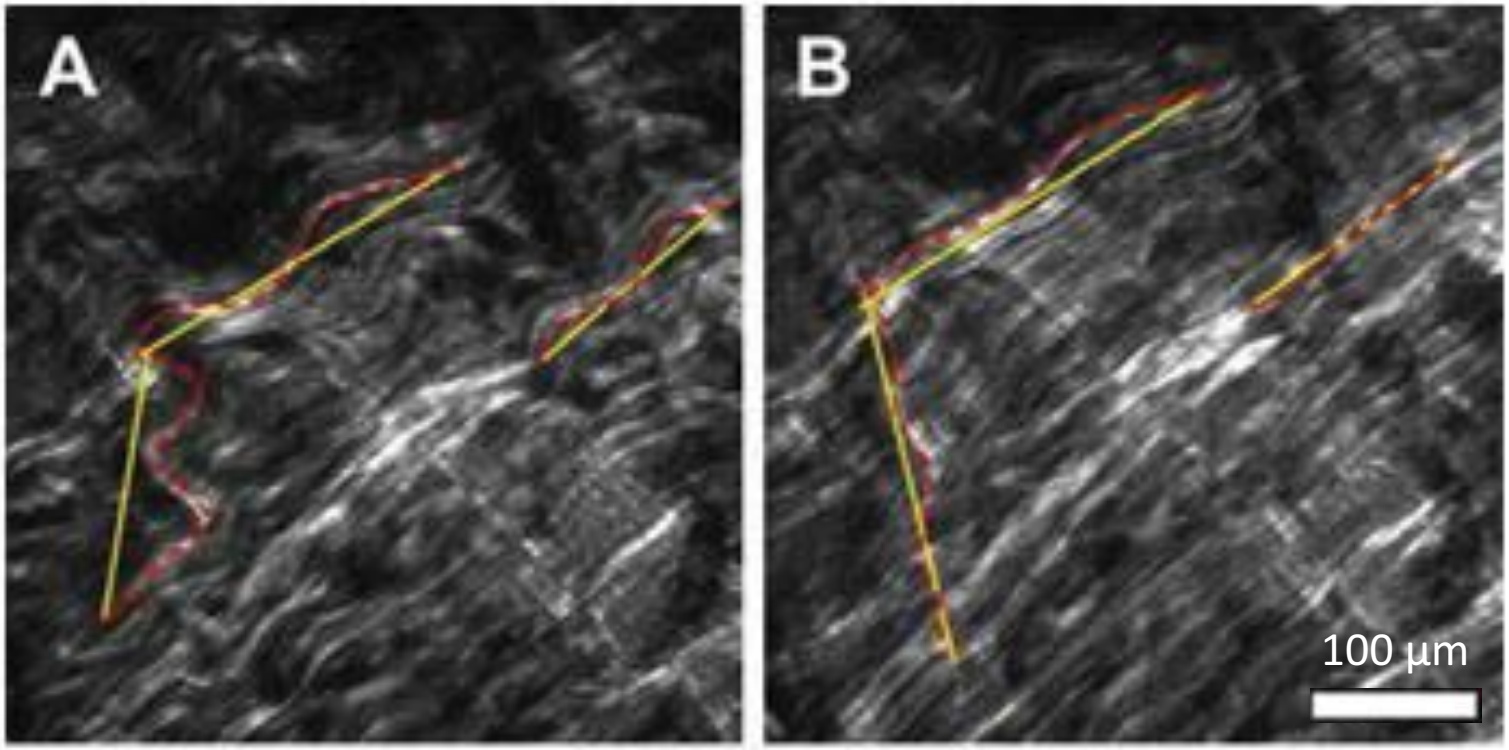




Collagen Fiber Undulation



Collagen Fiber Undulation



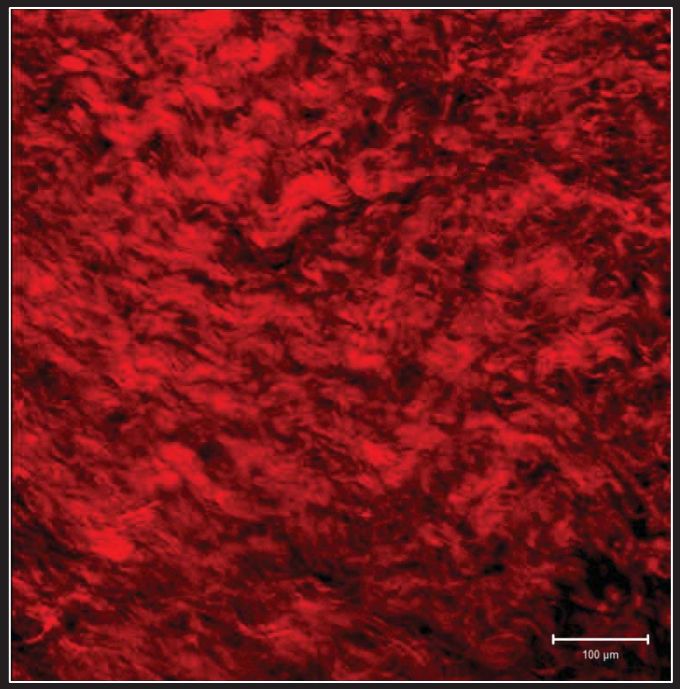
Chord Length (C)

Total Fiber Length (T)

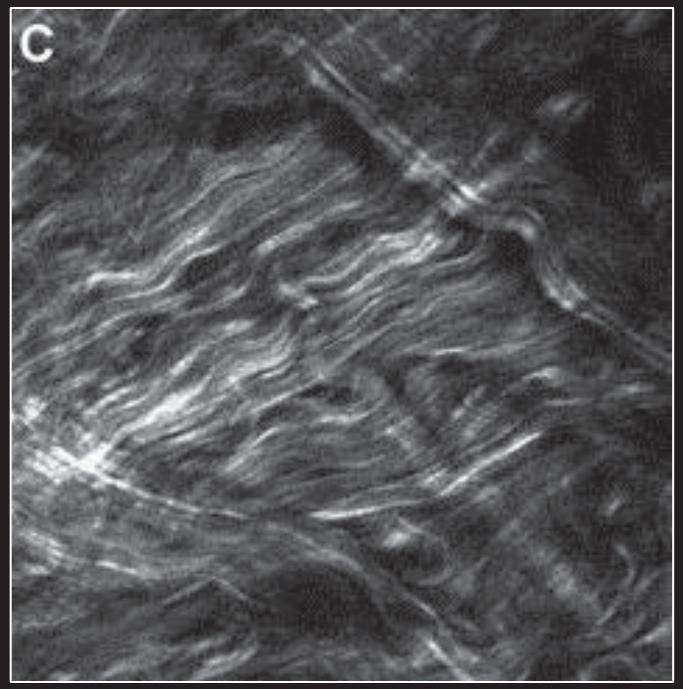
$$\% \text{ Engagement} = \frac{T}{C} \cdot 100$$

Wang et al. Journal of Biomechanics, 2013.

Collagen Structure



Optic Nerve Sheath



Arterial Adventitia

Beal et al. Journal of Surgical Research, 2013.

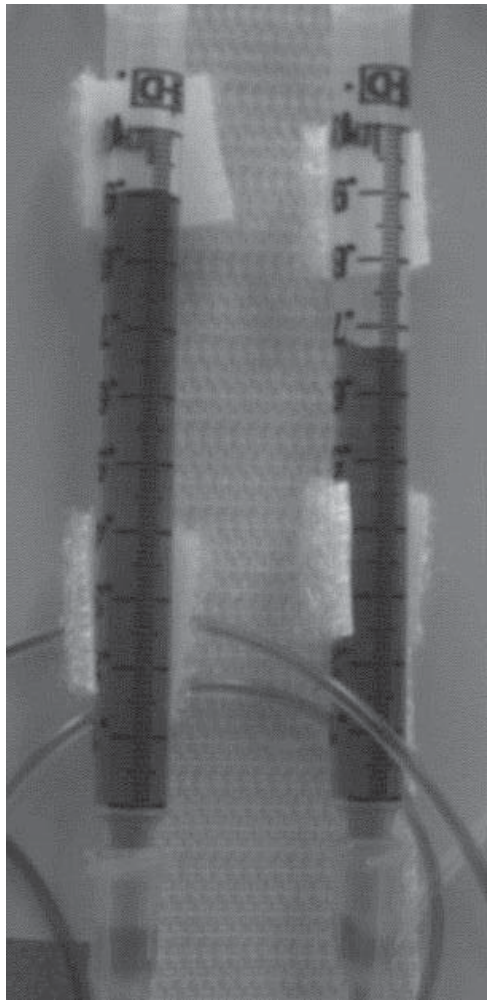
Blood Vessel Behavior

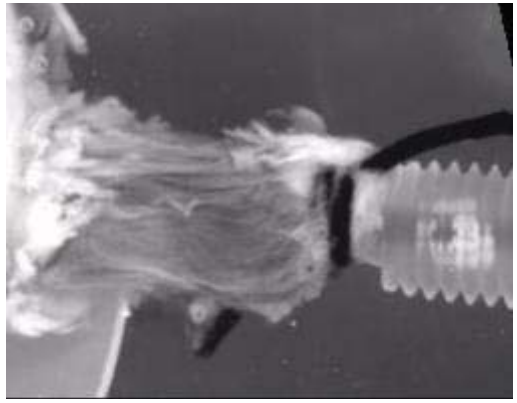
- Remodel in response to high pressures
- Wall thickens to reduce stress on cells

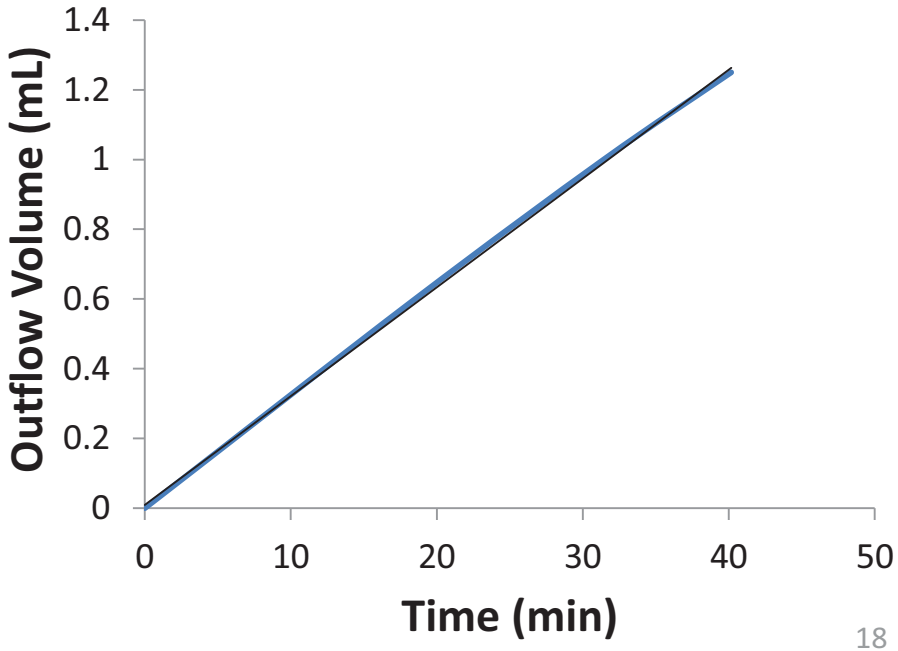
$$\sigma = \frac{Pr}{h}$$

- Appear to remodel towards target stresses

Permeability-Experimental Setup







Permeability-Results

$$K = \frac{V}{P \cdot A \cdot t}$$

V: outflow volume (µL)
P: pressure (mm Hg)
A: optic nerve surface area (cm^2)
t: time (s)

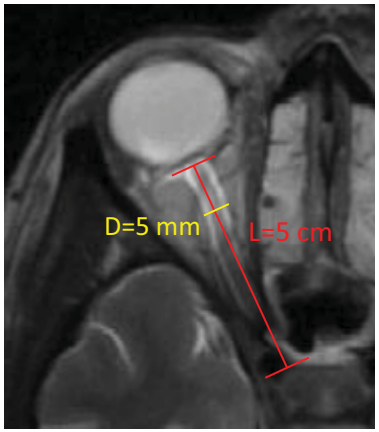
Permeability ($\mu L/min/cm^2/mm\ Hg$)
0.79±0.12 (n=17)

Estimation for Humans:

$Outflow\ Rate = K \cdot P \cdot A = 125 \frac{mL}{day}$ at 7 mm Hg

20% of daily CSF production

$$A = 2 \cdot \pi \cdot D \cdot L$$



Geeraerts et al. Critical Care, 2008.

Summary

- Optic nerve sheath exhibits typical soft tissue behavior:
  - Preconditioning effect in the early cycles of cyclic pressure diameter testing
  - Repeatable behavior following the fourth pressure-diameter cycle
  - Nonlinear stiffening at pressures
  - Anistropic behavior due to collagen orientation
- Structure and behavior appears to be similar to the adventitia
- High permeability suggests CSF drainage could play an important role in VIIP syndrome

Limitations

- Peeling away the meninges could cause structural damage
- Lack of availability of long human optic nerves
- Post mortem effects on permeability

Future Directions

- Quantify microstructural changes during mechanical loading

- Incorporate results into computational models of VIIP syndrome
  - Help identify possible interventions

Acknowledgements

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